EU ETS emission reductions through fuel-switching

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Outline

Key question that is addressed

- Has the EU ETS contributed to emission reductions?
  - Possibly yes; because of allowance pricing
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- Opportunities for emission reductions in the power generation industry
  - Short-term: "fuel-switching"
  - Long-term: carbon-free capacity accumulation
- Short-term fuel-switching:
  - Substitute coal-fired generation with gas-powered generation
  - Possible within the EU by: (i) generator, (ii) nationally, and (iii) regionally

The literature

- Does the allowance price depend on fundamentals? Hintermann (2010, JEEM), Koch et al (2016, JEEM), Koch et al (2014, EP), Aatola(2012, EE), Rickels(2014, GER)
  - Mostly no. Prices depend on some but not all relevant fundamentals

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  - Mostly no. Prices depend on some but not all relevant fundamentals
- Do generators pass-through emission costs to wholesale markets?
  Sijm et al (2008, CP), Fabra and Reguant (2014, AER), Hintermann (2016, JAERE)
  - Yes. Generators completely pass-through emission costs

Contribution

1. Integrated structural framework through which to assess the efficiency of an emission trading system
    1.1 Evaluate empirical outcomes against theoretical benchmarks
    1.2 This way we can pinpoint where the market is failing

A general model of fuel-switching

Objective: maximize power generation revenues net of generation costs

$$J(\bullet) = \max_{g_t, c_t} \mathbb{E}_k \int_{t \geq k}^{\infty} \rho_t \left(p^e \left(E_t, y_t \right) e(g_t, c_t) - p_t^g g_t - p_t^c c_t - p_t^x x_t \right) dt$$

ρ discount factor; p^e, p^g, p^c, p^x electricity, gas, coal, & allowance prices; E market electricity supply; e agents supply; y demand shift; g gas; c coal; a banked allowances; α^y, α^x drift terms; σ^y, σ^x volatility component; ϕ^g, ϕ^c intensities

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Do this subject to evolution of bank and price shocks:

$$\dot{a}_t = x_t - \phi^g g_t - \phi^c c_t$$
$$dy_t = \alpha^y \left(y_t \right) dt + \sigma^y \left(y_t, e_t \right) dz_t^y$$
$$dp_t^x = \alpha^x \left(p_t^x \right) dt + \sigma^x \left(p_t^x, a_t \right) dz_t^x$$

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Equilibrium conditions

Set price to marginal production cost:

$$p^e = \frac{1}{\vartheta e_g(g,c)} p^g + \frac{\phi^g}{\vartheta e_g(g,c)} p^x$$
$$p^e = \frac{1}{\vartheta e_c(g,c)} p^c + \frac{\phi^c}{\vartheta e_c(g,c)} p^x$$

ϑ Lerner index; p^e, p^g, p^c, p^x electricity, gas, coal, & allowance prices; e_g, e_c marginal product of gas and coal; ϕ^g, ϕ^c intensities of coal and gas; g gas; c coal

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Whereby eliminating p^e gives:

$$p^x = \frac{e_c}{(\phi^c e_g - \phi^g e_c)} p^g - \frac{e_g}{(\phi^c e_g - \phi^g e_c)} p^c$$

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Equilibrium conditions

Optimal banking condition:

$$(1/dt)\,\mathbb{E}_t d\left(p^x\right) = \sigma^x \sigma^x_a J_{p^x p^x} + \sigma^e \sigma^e_e e_g J_{yy} + \sigma^e \sigma^e_e e_c J_{yy} + r p^x$$

ρ discount factor; p^e, p^g, p^c, p^x electricity, gas, coal, & allowance prices; E energy supply; y demand shift; g gas; c coal; a banked allowances; α^y, α^x drift terms; σ^y, σ^x volatility component; ϕ^g, ϕ^c intensities

Findings

- An active fuel-switching mechanism is prevalent but likely limited by trading frictions (both traded and non-traded frictions)

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- For several EU ETS countries, allowance prices consistently drive dispatch choices of coal vis-à-vis gas and vice versa
- The demand for allowance banking is explained neither by risk nor scarcity premiums, but rather by random historical shocks

Data and sources

- Financial data collected from DataStream
  - Gas futures prices (TTF, NBP, ZEE)
  - Coal futures prices (API2)
  - Electricity futures prices (DE, NL, UK, BE, IT, FR, NDPL)
  - Stock indices and interest rates

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  - Stock indices and interest rates
- Weather data collected from KNMI
  - wind gust, sunshine duration, average temperature, rainfall
- Other controls
  - time and season indicators
  - dummies for extreme movements

Results I:

$$p_t^x = \beta_1 p_t^g + \beta_2 p_t^c + X_t \beta + \epsilon_t$$

	Short-run propensities				Long-run propensities
	(1) Static	(2) Dynamic	(3) Robust	(4) Non par.	(5)
Natural gas (€/mWH)	0.179*** (0.057)	0.162*** (0.052)	0.203*** (0.049)	0.140*** (0.043)	0.179*** (0.058)
Coal (€/mWH)	-0.199** (0.078)	-0.182*** (0.067)	-0.190*** (0.067)	-0.152** (0.059)	-0.201*** (0.075)
Auto-regressive lag	No	Yes	No	No	No
N	539	539	539	539	539
adj. R-sq	0.493	0.501	0.479	0.504	0.573

Results II

gas-fired: $p_t^e = \beta_1 p_t^g + \beta_2 p_t^x + X_t \beta + \epsilon_t$
coal-fired: $p_t^e = \beta_1 p_t^c + \beta_2 p_t^x + X_t \beta + \epsilon_t$

	German	Dutch	U. Kingdom	Belgian	Italy	France	Nordpool
	(2) 2SLS	(4) 2SLS	(6) 2SLS	(8) 2SLS	(10) 2SLS	(12) 2SLS	(14) 2SLS
PANEL A: natural gas equation (TTF)							
Natural gas (€/MWh)	1.204***	1.540***	1.348***	1.584***	1.114***	2.038***	1.190***
	(0.100)	(0.096)	(0.110)	(0.176)	(0.109)	(0.187)	(0.098)
Allowance (€/tCO2)	0.443**	0.417**	0.532**	0.502	0.589**	0.586#	0.449**
	(0.201)	(0.192)	(0.221)	(0.373)	(0.243)	(0.374)	(0.196)
N	539	539	539	505	495	539	537
Adj R-squared	0.400	0.476	0.358	0.365	0.448	0.424	0.401
PANEL D: coal equation (CIF ARA API2)							
Coal (€/MWh)	2.071***	2.287***	2.581***	3.075***	2.446***	2.961***	2.053***
	(0.301)	(0.312)	(0.328)	(0.611)	(0.374)	(0.560)	(0.294)
Allowance (€/tCO2)	0.972***	1.100***	1.121***	1.243***	1.177***	1.490***	0.964***
	(0.212)	(0.220)	(0.231)	(0.394)	(0.254)	(0.396)	(0.208)
N	539	539	539	505	495	539	537
Adj R-squared	0.289	0.274	0.253	0.289	0.374	0.319	0.287

Results III

$\Delta p_t^x = \beta_1 \sigma_t^e + \beta_2 \sigma_t^x + \beta_3 p_t^x + X_t \beta + \epsilon_t$

Thank you

Results I-Robustness

Variable	month-ahead futures							year-ahead futures		
	(1) Outliers	(2) Controls	(3) Zeebrugge	(4) NBP	(5) Phase II	(6) Phase III	(7) Phase I - III	(8) 2008-2018	(9) 2009-2015	(10) 2006-2010
Natural gas (EUR/mWH)	0.224***	0.178***	0.126**	0.117**	0.177**	0.184**	0.105***	0.326***	0.422***	0.357***
	(0.080)	(0.057)	(0.054)	(0.049)	(0.082)	(0.086)	(0.039)	(0.076)	(0.096)	(0.099)
Coal (EUR/mWH)	-0.209*	-0.205**	-0.177**	-0.169**	-0.215**	-0.199#	-0.147**	-0.180*	-0.357***	-0.236*
	(0.118)	(0.080)	(0.078)	(0.077)	(0.109)	(0.122)	(0.068)	(0.097)	(0.132)	(0.129)
N	539	539	539	539	260	279	689	537	364	210
adj. R-sq	0.121	0.493	0.487	0.487	0.441	0.529	0.510	0.501	0.484	0.416

Results II - Robustness

	Electricity price (€/MWh)													
	German Baseload		Dutch Baseload		UK Baseload		Belgian Baseload		IT Baseload		French Baseload		Nordpool Baseload	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS	(7) OLS	(8) 2SLS	(9) OLS	(10) 2SLS	(11) OLS	(12) 2SLS	(13) OLS	(14) 2SLS
PANEL A: natural gas equation (TTF)														
Natural gas (€/MWh)	1.174***	1.204***	1.514***	1.540***	1.308***	1.348***	1.606***	1.584***	1.111***	1.114***	2.026***	2.038***	1.166***	1.190***
	(0.128)	(0.100)	(0.116)	(0.096)	(0.188)	(0.110)	(0.197)	(0.176)	(0.149)	(0.109)	(0.258)	(0.187)	(0.127)	(0.098)
Allowance (€/tCO2)	0.660***	0.443**	0.607***	0.417**	0.831***	0.532**	0.205	0.502	0.582***	0.589**	0.654***	0.586#	0.620***	0.449**
	(0.167)	(0.201)	(0.165)	(0.192)	(0.208)	(0.221)	(0.251)	(0.373)	(0.182)	(0.243)	(0.247)	(0.374)	(0.171)	(0.196)
N	539	539	539	539	539	539	505	505	495	495	539	539	537	537
Adj R-squared	0.420	0.400	0.492	0.476	0.386	0.358	0.363	0.365	0.456	0.448	0.428	0.424	0.417	0.401
PANEL B: natural gas equation (NBP)														
Natural gas (€/MWh)	0.909***	0.930***	1.263***	1.284***	1.055***	1.079***	1.268***	1.259***	0.883***	0.895***	1.601***	1.619***	0.919***	0.935***
	(0.114)	(0.088)	(0.103)	(0.083)	(0.156)	(0.096)	(0.175)	(0.147)	(0.132)	(0.097)	(0.243)	(0.162)	(0.107)	(0.086)
Allowance(€/tCO2)	0.759***	0.399*	0.714***	0.357*	0.932***	0.501**	0.234	0.263	0.628***	0.552**	0.818***	0.475	0.717***	0.401**
	(0.189)	(0.206)	(0.188)	(0.195)	(0.220)	(0.225)	(0.256)	(0.374)	(0.197)	(0.248)	(0.267)	(0.381)	(0.192)	(0.201)
N	539	539	539	539	539	539	505	505	495	495	539	539	537	537
Adj R-squared	0.392	0.363	0.486	0.461	0.369	0.330	0.354	0.354	0.430	0.419	0.410	0.401	0.394	0.368
PANEL C: natural gas equation (ZEE)														
Natural gas (€/MWh)	1.057***	1.073***	1.398***	1.412***	1.234***	1.255***	1.360***	1.348***	0.911***	0.918***	1.792***	1.800***	1.047***	1.060***
	(0.109)	(0.091)	(0.102)	(0.087)	(0.163)	(0.099)	(0.180)	(0.156)	(0.137)	(0.098)	(0.258)	(0.171)	(0.113)	(0.090)
Allowance (€/tCO2)	0.769***	0.544***	0.741***	0.546***	0.941***	0.652***	0.256	0.490	0.653***	0.614**	0.849***	0.724*	0.733***	0.543***
	(0.185)	(0.201)	(0.183)	(0.191)	(0.212)	(0.218)	(0.257)	(0.374)	(0.191)	(0.247)	(0.259)	(0.376)	(0.189)	(0.197)
N	539	539	539	539	539	539	505	505	495	495	539	539	537	537
Adj R-squared	0.417	0.391	0.502	0.479	0.402	0.366	0.354	0.355	0.435	0.424	0.421	0.413	0.414	0.390
PANEL D: coal equation (CIF ARA API2)														
Coal (€/MWh)	1.997***	2.071***	2.213***	2.287***	2.490***	2.581***	2.887***	3.075***	2.411***	2.446***	2.880***	2.961***	1.981***	2.053***
	(0.704)	(0.301)	(0.670)	(0.312)	(0.710)	(0.328)	(0.640)	(0.611)	(0.420)	(0.374)	(1.034)	(0.560)	(0.636)	(0.294)
Allowance (€/tCO2)	0.913***	0.972***	0.944***	1.100***	1.104***	1.121***	0.510*	1.243***	0.881***	1.177***	1.108***	1.490***	0.870***	0.964***
	(0.192)	(0.212)	(0.191)	(0.220)	(0.197)	(0.231)	(0.276)	(0.394)	(0.200)	(0.254)	(0.286)	(0.396)	(0.201)	(0.208)
N	539	539	539	539	539	539	505	505	495	495	539	539	537	537
Adj R-squared	0.308	0.289	0.287	0.274	0.281	0.253	0.278	0.289	0.378	0.374	0.319	0.319	0.302	0.287

Engineering-based efficiencies and emission intensities

	Germany		Netherlands		U. Kingdom		Belgium		Italy		France		Spain		Portugal	
	2005	2016	2005	2016	2005	2016	2005	2016	2005	2016	2005	2016	2005	2016	2005	2016
PANEL A: power plant efficiency in percent (e_g and e_c)																
Natural gas	0.404	0.444	0.418	0.503	0.511	0.526	0.484	0.512	0.454	0.464	0.480	0.480	0.629	0.556	0.507	0.371
Coal	0.377	0.371	0.418	0.411	0.369	0.370	0.379	0.409	0.372	0.380	0.368	0.383	0.375	0.385	0.327	0.388
PANEL B: heat rate in MWh Fuel per MWh Electricity (e_g^{-1} and e_c^{-1})																
Natural gas	2.472	2.252	2.390	1.990	1.955	1.902	2.065	1.953	2.203	2.155	2.083	2.083	1.589	1.798	1.973	2.699
Coal	2.655	2.696	2.390	2.433	2.710	2.703	2.636	2.446	2.690	2.632	2.717	2.612	2.669	2.596	3.054	2.576
PANEL C: emission intensities after combustion in tCO2 per MWhe ($e_g^{-1}\phi^g$ and $e_c^{-1}\phi^c$)																
Natural gas	0.455	0.415	0.440	0.366	0.360	0.350	0.380	0.359	0.405	0.397	0.383	0.383	0.292	0.331	0.363	0.497
Coal	0.904	0.918	0.814	0.829	0.923	0.921	0.898	0.833	0.916	0.896	0.925	0.890	0.909	0.884	1.040	0.877
Coal/Gas ratio	1.987	2.215	1.850	2.263	2.564	2.631	2.362	2.318	2.259	2.259	2.413	2.320	3.108	2.672	2.864	1.766

Time series properties

	2008 to 2018						2005 to 2010					
Variable	Obs.	Mean	SD	R. t. Var	AC(1)	AC(2-8)	Obs.	Mean	SD	R. t. Var	AC(1)	AC(2-8)
Coal												
API2	539	-0.04	3.04	1.000	0.330	0.062	311	0.16	3.40	1.000	0.385	0.090
ICE Rotterdam year-ahead	538	-0.02	3.11	1.021	0.265	0.030	210	0.27	3.69	1.087	0.333	0.060
Gas												
ICE TTF month-ahead	539	-0.03	4.12	1.352	0.193	0.025	306	0.19	6.53	1.922	0.235	0.023
ICE TTF year-ahead	539	-0.04	3.27	1.075	0.123	0.012	306	0.16	3.72	1.097	0.347	0.014
ICE Zebrugge month-ahead	539	-0.03	4.49	1.475	0.167	0.011	172	0.21	6.39	1.880	0.196	0.012
ICE Zebrugge year-ahead	539	-0.03	3.20	1.051	0.140	0.024	311	0.17	4.33	1.276	0.116	0.039
ICE NBP month-ahead	539	-0.03	4.75	1.560	0.158	0.013	163	-0.02	6.54	1.925	0.179	0.004
ICE NBP year-ahead	539	-0.03	3.58	1.175	0.231	0.005	163	-0.02	4.53	1.333	0.303	0.031

Results III

$$p^x = \frac{e_g^{-1}(g,c)}{\left(\phi^c e_c^{-1}(g,c) - \phi^g e_g^{-1}(g,c)\right)} p^g - \frac{e_c^{-1}(g,c)}{\left(\phi^c e_c^{-1}(g,c) - \phi^g e_g^{-1}(g,c)\right)} p^c$$